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Benchmarking sensor fusion capabilities of an integrated instrumentation package

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ABSTRACT

Quantifying and mitigating environmental risks presented by marine energy conversion systems requires a variety of sensors (active acoustic, passive acoustic, and optical). The operation of these sensors must satisfy three directives to be effective: (1) do not alter the environment through operation of sensors; (2) capture rare events; and (3) do not accrue unmanageable volumes of low-value data. This requires integrating sensors into a single package, rather than operating them independently. The Adaptable Monitoring Package is an integrated instrumentation package that combines a multibeam sonar, acoustic camera, current profiler, optical cameras, and an array of hydrophones. The capabilities and limitations of the AMP sensors were benchmarked using cooperative targets, and real-time target tracking and detection was used to detect opportunistic targets (e.g., diving birds, seals). During an initial deployment, automatic detection of opportunistic targets achieved a 58% true positive rate and a 99% true negative rate (100% corresponding to an ideal system in both cases). In post-processing, target tracking data were used to evaluate automatic target classification capabilities using a k-nearest neighbor algorithm. Results suggest that real-time target classification should be possible and enable integrated instrumentation systems to meet the monitoring needs of marine energy deployments.

1. Introduction

There is significant uncertainty surrounding the environmental effects of marine renewable energy development. While the potential risks that marine energy converters pose to marine environments have been identified and prioritized, their significance remains uncertain [1]. If these risks are quantified they may be "retired", if shown to be of little significance, or mitigated, if found to be significant [1]. In collecting data to quantify risk, there are three principle directives, presented in order of priority: (1) to not affect the environment by conducting monitoring; (2) to capture as many rare events as possible so as to increase statistical power; and (3) to avoid accumulating data at a rate that is impractical to archive and analyze. While no individual sensor can provide all necessary environmental data while satisfying these directives, integrated instrumentation can do so by enabling acquisition with multiple sensor types, allowing data classification at the time of collection, and controlling sensor operation and data acquisition in real time.

Here, we frame integrated instrumentation development as a progression through three generations. The first generation involves development of a common hardware backbone to allow for power and data transfer over a cable to shore. For this generation of integration, deployment, maintenance, and recovery of instruments present a non-trivial ocean engineering

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problem, in addition to the nonrecurring engineering development for power and data distribution [2]. First-generation systems allow multiple instruments to collect simultaneous information and continuous data acquisition from all sensors will not miss rare events (meeting directive 2). However, this mode of operation risks affecting animal behavior (through light and/or sound) and can incur petabyte-scale storage costs for continuous acquisition from high-bandwidth sensors. This storage and analysis backlog is sometimes colloquially referred to as a "data mortgage" [3].

Second-generation integrated packages provide a common software framework for all data streams. This allows sensors to be synchronized and acquisition periods to be coordinated between instruments. The latter is particularly important if there is a possibility of mutual interference between sensors (e.g., "cross-talk" for active acoustics [4]). If operated on a duty cycle, a second-generation system can reduce data storage requirements and limit use of sensors that may affect animal behavior. This means that second-generation systems can simultaneously meet directives 1 and 3, but at the cost of not meeting directive 2 (i.e., potentially missing rare events). Second-generation integration has a significant implementation cost, because a common software framework is not generally supported by manufacturer software included in the price of individual sensors.

The third-generation of integration encompasses the real-time analysis of available data streams for target classification and sensor control. This requires processing individual data streams (e.g., target detection in multibeam sonar data) and fusing multiple data streams (e.g., comparing the trajectory of that target to the tidal currents measured by a current profiler) to provide operational awareness of the surrounding environment. Results of real-time awareness can be used to trigger data acquisition only when there is a high probability that a target of interest is detectable (e.g., a marine mammal), reducing the risk of a data mortgage while capturing rare events. Additionally, this awareness can limit use of sensors which may alter the environment to periods when there are sensitive targets present. For example, a third-generation system can limit artificial illumination for optical cameras to only periods when there is a high-priority target within the optical camera field of view. Consequently, third-generation systems may be able to simultaneously meet all three environmental monitoring directives.

Several first and second generation integrated packages have been deployed at marine energy sites to date (i.e., [5–8]). These packages support a range of sensors – including multibeam sonars, hydrophones, echosounders, acoustic Doppler current profilers (ADCPs), fluorometers, and optical cameras. Because of the number of high and medium-bandwidth instruments (multibeam sonar, optical cameras, echosounders), continuous acquisition from integrated packages rapidly accrues vast amounts of data, and each of these existing systems has relied on extensive post-processing of raw data streams [9].

This paper describes the development and benchmarking of an integrated instrumentation package for third-generation operation, the Adaptable Monitoring Package (AMP, shown in Fig. 1). The AMP currently supports active acoustics (multibeam sonar, acoustic camera, and current profiler), passive acoustics (an array of hydrophones), and optical cameras. The benefits of third-generation capabilities were evaluated by comparing data acquired on a sparse duty-cycle to data acquired by real-time target detection using the acoustic camera and multibeam sonar data streams (i.e., "triggered" acquisition). Automatic classification of detected targets was then tested in post-processing. In addition, "cooperative" targets were used to benchmark individual sensor performance. Results confirm several of the hypothesized benefits of third-generation integration, but also demonstrate the challenges to achieving this. Throughout this paper, the following terms have specific meaning:

- *Detection*: The recognition of a target within the AMP field of view.
- *Classification*: the assignment of a target to a particular class (e.g., diving bird).
- *Identification*: specific assignments within a class, potentially to the level of a species (e.g., identifying a diving bird as a Cepphus Columba).

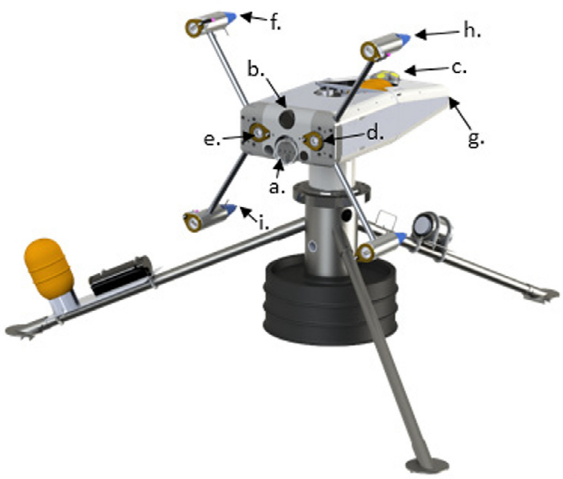

Fig. 1. The Adaptable monitoring package on its docking station. Sensors labels are detailed in Table 1.

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